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AUTOMATED VISIBILITY MEASUREMENTS WITH A HORIZON SCANNING IMAGER
VOLUME I: TECHNICAL DISCUSSION

R. W. Johnson
M. E. Karr
J. R. Varah

University of California, San Diego
Marine Physical Laboratory
San Diego, CA 92152-6400

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Contract Manager
Atmospheric Structure Branch

DONALD D. GRANTHAM, Chief
Atmospheric Structure Branch
Atmospheric Sciences Division

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R. W. Johnson
M. E. Karr
J. R. Varah

7. Performing Organization Name(s) and Address(es).
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San Diego, CA 92152-6400

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This two volume report describes the continued development and enhancement of an electro-optical system designed for the automatic acquisition and archival of local horizon imagery specifically tailored to the determination and assessment of daytime sector visibilities and subsequently their spatial and temporal variabilities. Volume I describes the extension of the system's capabilities into the nighttime regime and presents preliminary night imagery suitable for use in the identification of distant lights as visibility targets. Techniques for improving daytime target selection and characterization are also discussed. Volume II contains engineering documentation, software documentation, preliminary operations manual and preliminary field test plan.

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1.0 INTRODUCTION

The Optical Systems Group at the Marine Physical Laboratory of Scripps Institution of Oceanography has produced a compact and reliable system for the automatic acquisition and archival of local horizon imagery specifically tailored to the determination and assessment of daytime sector visibilities, and subsequently their spatial and temporal variabilities.

Original operational concepts, prototype hardware and software, along with historical background information related to the development of this system has been reported previously in GL-TR-89-0061, Johnson, et al, (1989).

This present report, Scientific Report No. 1, Vol. I, discusses the continued development and enhancement of the HSI system, incluc.ing extension of system capabilities into the nighttime regime, and preliminary testing of an automatic procedure for optimum specification of target characteristics.

Included as Volume II, are summaries and listings of appropriate system software packages, hardware engineering drawings and supporting documentation previously provided as Technical Note No.'s 213 and 216.

2.0 THE HORIZON SCANNING IMAGER (HSI)

The Horizon Scanning Imager (HSI), and its companion system the Whole Sky Imager (WSI) have each been described in Johnson, et al, (1989) as well as the accompanying Vol. II of this report, consequently only Figures 2-1 and 2-2 are included herein for the convenient re-familiarization of the reader.

2.1 The As-Built Composite HSI/WSI

As noted in the Volume II references and illustrated in Figure 2-1, the prototype visibility and cloud detection systems were fabricated as two separate hardware/software entities which need not necessarily be integrated into a single electro-mechanical unit. Each may stand alone and function independently, or if desired, under the control of the composite HSI/WSI system software the two sub-assemblies may be operated jointly under an optionally specified time-share duty cycle. A nominal automatic duty cycle is for the HSI to run horizon sweeps each minute for eight minutes and every ten minutes insert a cloud cover measurement. In this mode, the system will display its output products of sector visibilities and cloud cover to the CRT display and/or output the data to printer for hardcopy. It will also, at the operators discretion, archive both original imagery and derived numerical products to its EXABYTE tape sub-system for later retrieval and analysis.

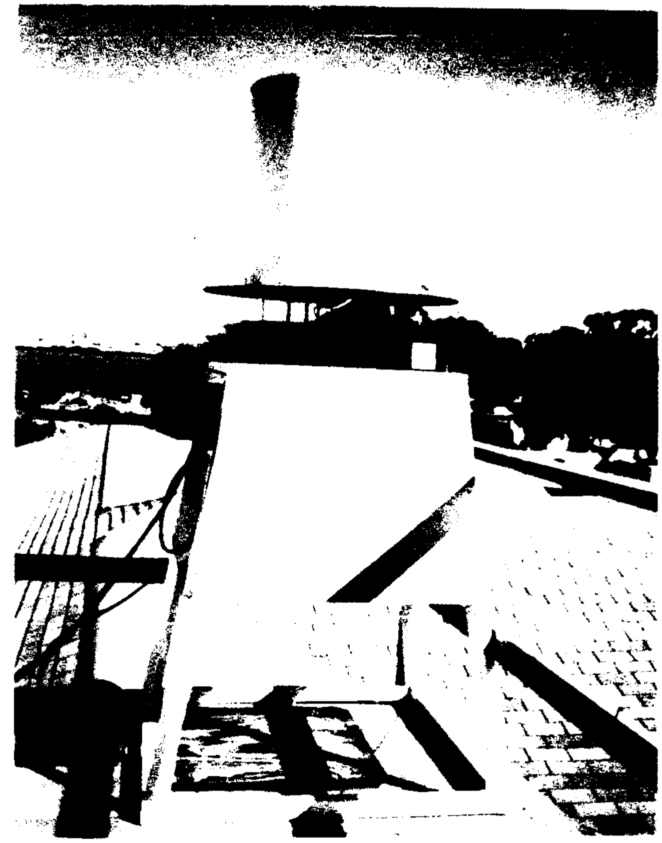


Fig. 2-1 Composite HSI/WSI As-built Field Installation

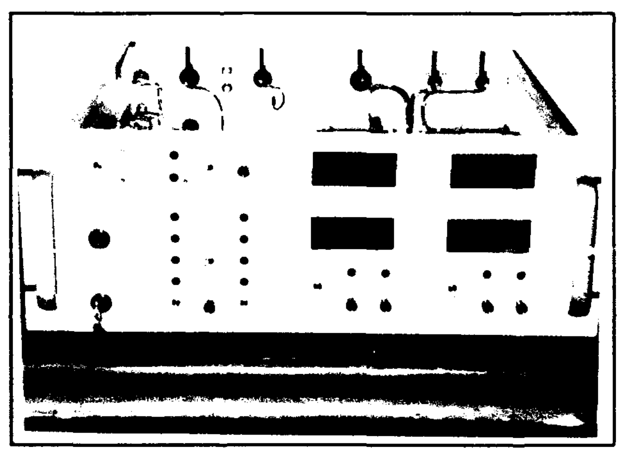


Fig. 2-2 Composite HSI/WSI Accessory Control Panel

2.2 Functional Characteristics

The basic functional characteristics of both the HSI and the WSI stand alone systems have remained essentially as described in Johnson, et al, 1989. The general concept of their operational sequences can be illustrated as in Figures 2-3 and 2-4. These diagrams have of course been simplified for clarity and do not include the myriad of housekeeping and control details that enable the automatic image acquisition sequences. These enabling details are for the most part contained in the various appendices which are combined as Volume II.

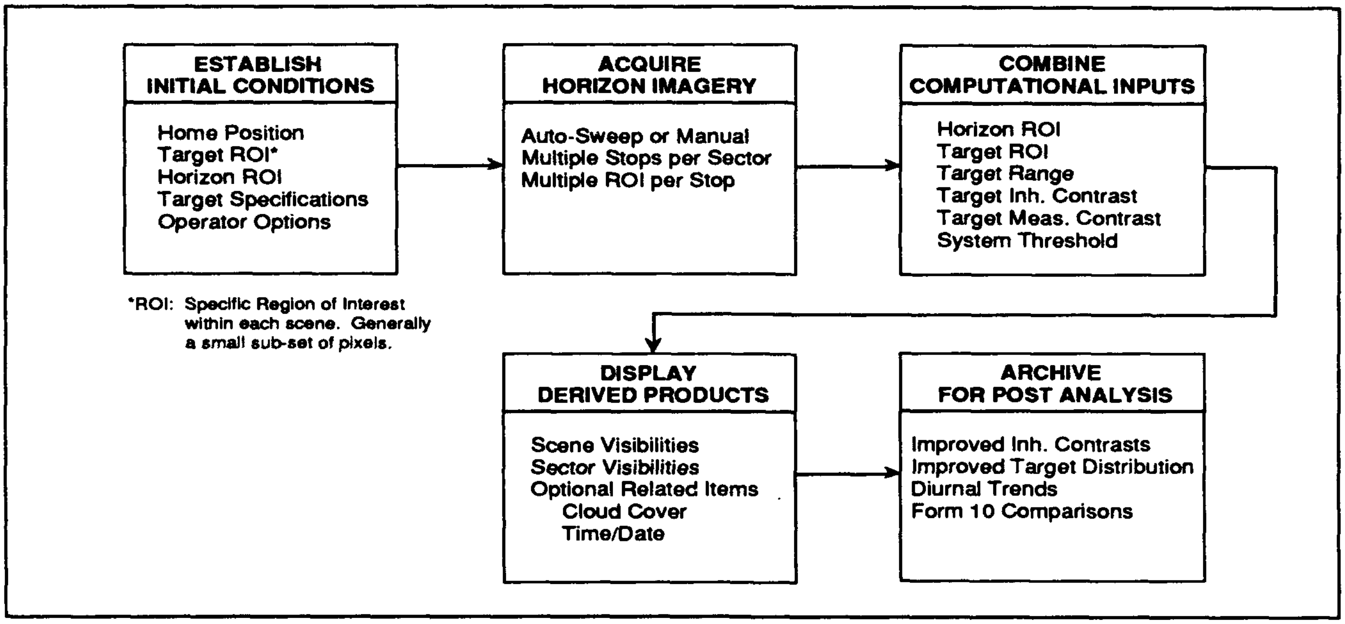


Fig. 2-3 HSI Procedural Flow Chart

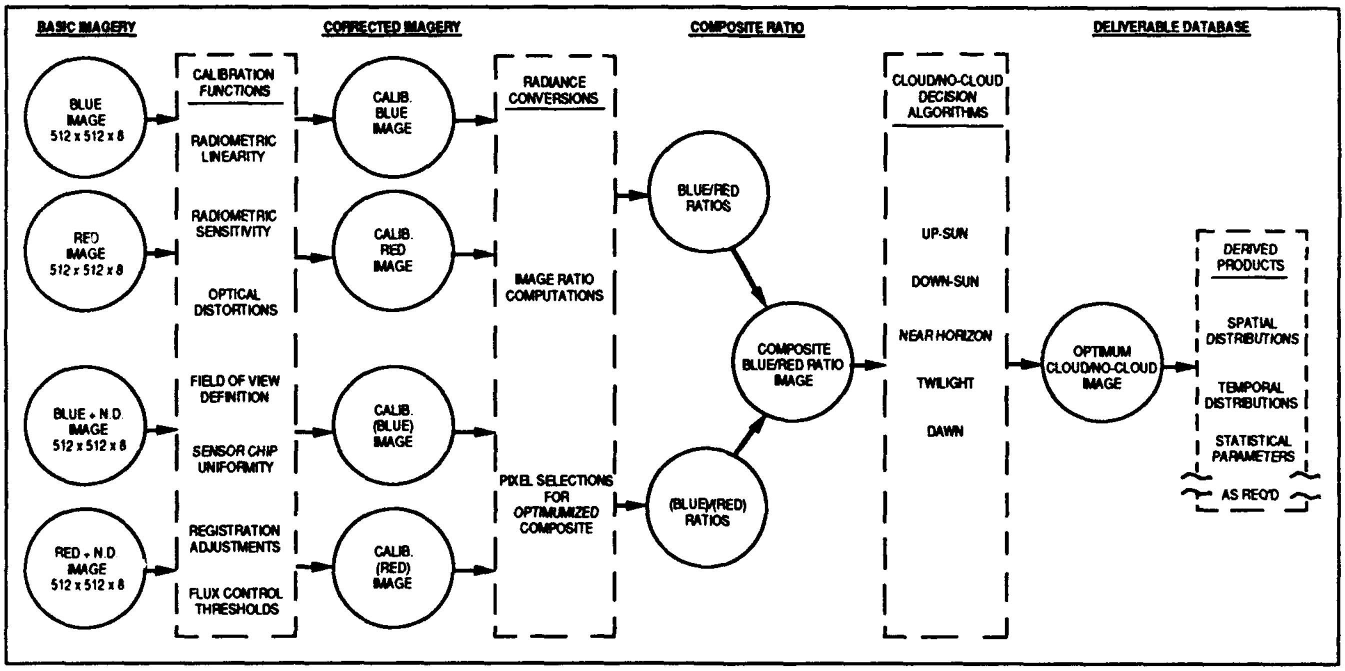


Fig. 2-4 WSI Basic Image Processing Flow Chart

The composite HSI/WSI system developed and refined under the current contractual effort, F19628-88-C-0154, is briefly described in Technical Note 216, which is included as part of Volume II. In this joint mode of operation, the individual characteristics of each subsystem as illustrated in Figures 2-3 and 2-4 are retained. Only the relative duty cycle associated with each subsystem is manipulated to provide the desired composite data base. The operator may choose to interrupt the normal minute by minute horizon sweeps as deemed appropriate to insert periodic whole sky image sets. The only procedural caveat is the procedural time required for the sequence illustrated in Figure 2-4. In its current "real-time cloud" configuration, the computational and archival processes require slightly less than two minutes.

3.0 REFINEMENTS ACCOMPLISHED

As discussed in Johnson, et al, 1989, the basic operational concepts of both the HSI and WSI were well developed and demonstrable. The two related systems however were running as fully independent devices. During the current development interval, 30 September 1988 through 30 September 1990, a variety of system configuration and operational procedure changes have been accomplished. The first, noted earlier in Section 2, was to merge elements of the two control codes to enable joint HSI/WSI operation through a single automatic controller. Several aspects of this system up-grade are commented upon in the following paragraphs.

3.1 Hardware

From a strictly hardware point of view, there have been essentially three major activities during the past two years that impacted the operational status of the HSI system. They were a) the conversion to, and relocation of the composite HSI /WSI system, b) the evaluation and selection of the hardware to be used in a nighttime system, and c) the assembly and operation of the Remote Field Test Station (RFTS).

a) Relatively early in this past development interval, the trapezoidal support frame illustrated in Figure 2-1 was provided for the HSI systems. These frame and enclosure sub-assemblies provided an improved mechanical stability for the rooftop installations, which in turn eliminated a diurnal misalignment of the optical path of sight, and thence a non-reproducibility in distant target registrations. Additionally, the enclosure provided a protective housing for the system's temperature control sub-system. This sub-system was a retrofit to replace the original air conditioner/ radiant heater forced air technique with a pumped liquid in a chiller/immersion heater scheme. The increased efficiency of the liquid system was substantial, reducing camera summertime operating temperatures from the low 30°C region down to the mid teens.

Also early in the interval, a change was made in the control computer from the original Zenith Z-248 class desktop to the Texas Micro Systems (TMI) version of the IBM/AT. This conversion was implemented to make the HSI controller the same as that used with the WSI. With this conversion completed, the additional steps needed to implement the composite HSI/WSI system were readily achievable. At this point, the composite Accessory Control Panels illustrated in Figure 2-2 were fabricated, the prototype composite housings shown in Figure 2-1 were assembled. Shortly thereafter the complete HSI/WSI system was relocated from the Geophysics Laboratory to their field site at OTIS Air National Guard Base. With this relocation accomplished, the system began its long term shakedown and testing with field unit #1 running under the auspices of the Geophysics Lab field team at OTIS, and field unit #2 running under MPL control at San Diego. At this point, both field units #1 and #2 were, and are now, physically identical units. Only developmental code undergoing de-bug is different in the MPL machine, from the operational code at OTIS. Engineering documentation related to the fabrication of these units are contained in Technical Note No. 224, included as part of Volume II.

b) The extension of HSI operations into the night time has been a highly desirable upgrade throughout the systems developmental lifetime. The broadly acknowledged need for this extension has only recently seemed within reach through the use of intensified video rate imagers and/or other slow scan devices. In the early stages of this current contract interval, several intensified video camera systems were evaluated for this application. Whereas each of the systems possessed a variety of attractive features, they were in general expensive and somewhat inflexible in their suitability for integrating into a fully automatic system such as the daytime HSI.

Discussions with the Electro-Optical Products Division of ITT resulted in a decision to acquire their Model F4767 Generation II image intensifier tube coupled to an 18mm:11mm fiber optic taper, in turn attached to a CID 21-28 solid state area array. The acquisition of these sub-assemblies enabled a simple and straightforward modification to the existing HSI systems with the retention of all MPL developed flexibilities and operational options. Further comment regarding these intensifiers and their application is contained in the following Section 4.

c) Once the testing of prototype low light level devices progresses beyond the mock-up stage, it is generally advantageous to move the testing out of the laboratory environment into the real world. The incentive being that the sooner one identifies the design transition problems the better. As noted in the following section, a Remote Field Test Station was established in the foothills near Jamul, CA, about 20 miles east of the MPL site on San Diego bay. Several illustrative scenes of and from this site are shown in Figures 3-1 through 3-6.

The RFTS camera installation is illustrated in Figures 3-1, 3-2 and 3-3. The overview in 3-1 shows the high point camera installation and vehicle containing the system's control console. The portable 10KW motor generator is not shown in this view of the

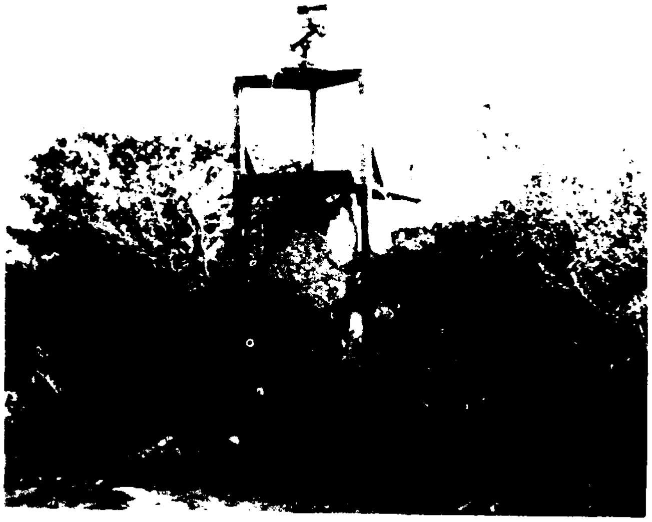


Fig. 3-1 Remote Field Test Station, Jamul, CA, overview

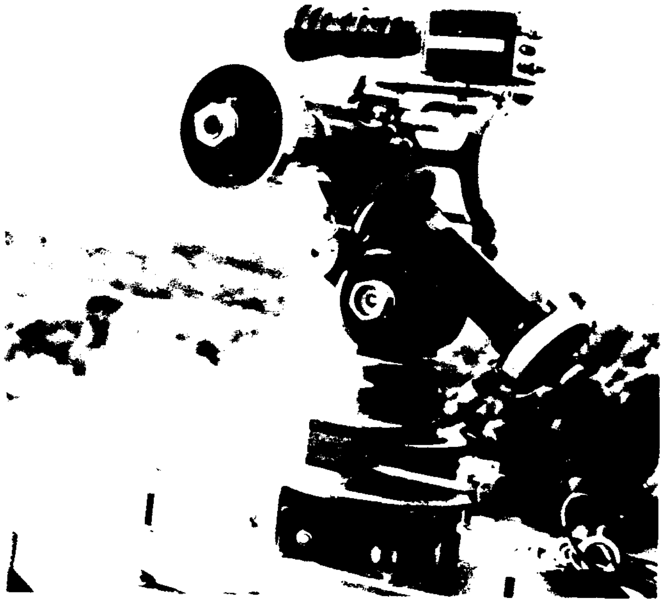


Fig. 3-3 RFTS, Close-up of Camera, w/Zoom Lens

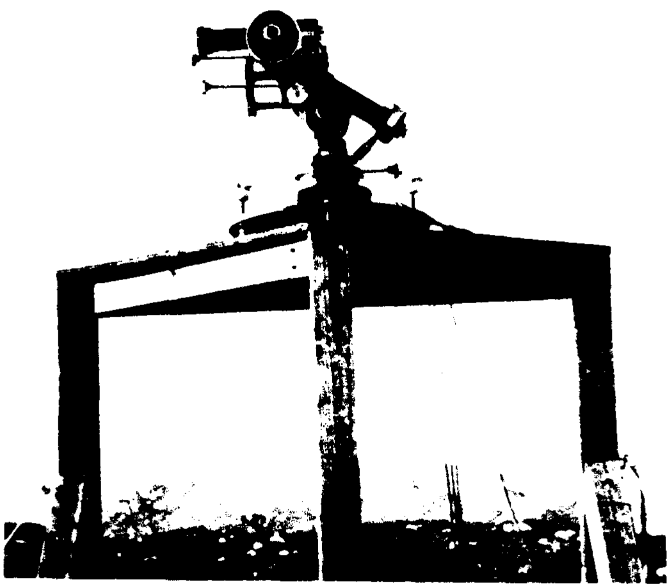


Fig. 3-2 RFTS, View from platform

Fig. 3-4 View to west from RFTS, Normal 50mm lens

site. Figure 3-2 illustrates the camera's equatorial mount, and the working platform used by the operator. Figure 3-3 is a close-up view of the camera assembly and its leveling plate. In these views the camera is shown with its 85 to 250mm zoom lens in place which allows the variety of magnifications shown in Figures 3-4, -5 and -6 without changing the mechanical set-up.

Figures 3-4, 3-5 and 3-6 show the view to the west from the RFTS. The first, Figure 3-4, is taken with a standard 50mm focal length lens and represents the view approximately as seen by the system operator. Attention should be directed to the rocky peak near the center of the scene. In the small gap immediately adjacent to its right side slope is the path of sight toward La Jolla. The scene shown in Figure 3-6 is a telephoto view through this gap which clearly shows the building complex which is slightly inland from the La Jolla campus, about 32 miles from the RFTS site. The scene shown in Figure 3-5 is a comparable telephoto view through the gap to the far left of the central rocky peak. In this scene one can clearly discern the structural complex of downtown San Diego and the

Fig. 3-5 View southerly of west, Telephoto toward Point Loma, @ 250mm

Fig. 3-6 View northerly of west, Telephoto toward La Jolla, @ 250mm

eastern side of Point Loma, the site of the Marine Physical Laboratory at about 30 miles from the RFTS.

The display of these telephoto views is primarily to familiarize the reader with the nature of the RFTS operational environment. Subsequent illustrations, taken at night with the camera's low light level options enabled, will show these same scenes to illustrate various nighttime capabilities.

With the low ambient light typically available during the night at the RFTS, performance of the various low light level sensor configurations could be readily evaluated. Electronic improvements to the control system were required to resolve a basic mismatch between the original 286 based CPU and the VS-100 frame grabber, and a new electronic video frame counter was required to control the selection of reproducible integration periods. While these tasks were non-trivial, they did yield, and the collection and archival of suitable night imagery was enabled.

3.2 Software

To a large degree, the software efforts during this most recent development interval have been related to the conversions necessary to implement the joint operation of the HSI and WSI sub-assemblies, the coding of a variety of display enhancements to improve the ease of operator interface for data evaluation, and the development of a preliminary methodology for determining optimum values of inherent contrast for use in the automatic visibility calculations. Descriptive summaries of these various software elements are contained in Technical Note No. 225, which is included as part of Volume II.

Although both the HSI and WSI systems have been running satisfactorily in either full automatic or interactive mode for some time, the efficient merging of these two initially independent software codes, along with code for processing WSI data to yield cloud results in near real-time, was not a trivial exercise. The choices in establishing a reasonable time share distribution were driven by both the one minute and ten minute data sequences existing in the original codes as well as the data storage requirements imposed by the on-line processing of the WSI imagery for cloud cover estimates. The current duty cycle of 15 minutes in Visibility mode followed by two minutes in Cloud Cover mode seems a good compromise that does not overly restrict retrieval and display options. Since a substantial number of modifications to programs SETUPVIS, AUTOVIS and a variety of EXABYTE utilities have been made to enable the current version of the composite system, no procedural changes are contemplated at this time, although substantial quantities of new code will be required to implement the planned conversion to Day/Night capability.

A second area of software development has been related to the improvement of the basic data values used in the calculation of visibility within each scene. In the fully automatic HSI system, target range, detection threshold and target inherent contrast are user specified while target apparent contrast is measured. The input values for target range are fixed. The detection threshold, which is actually the human detection threshold associated with the visibility definition, also can be specified at a fixed value. Thus, improvements in the specification of target inherent contrast are translated directly into improvement in the systems estimate of scene visibility. In an effort to insure using the darkest possible scene elements as visibility targets, and thus allow the targets specified inherent contrast to be estimated as close to the idealized value of minus one as possible, the system software was modified to select as an option, the darkest 20% of the pixel values in any Region of Interest (ROI) for use in the visibility calculation. In a fully optimized system, the actual value of target inherent contrast would be determined and specified at the instant of apparent contrast measurement. This obviously is not possible in a real world environment, however the closer the approximation the more reliable and reproducible will be the estimate of visibility. Thus, the need for the next set of software enhancements is made clear. One must devise a methodology to determine the time variant inherent contrast of each selected target ROI with its adjacent horizon.

The current software packages designed to assist in the development of preliminary approaches for extracting inherent contrast estimates from HSI imagery are designated TESTSETUPVIS and COSTUDY. Their general features are discussed in Technical Note No. 225. For the most part, these two developmental software packages enable one to acquire, archive and retrieve HSI imagery over extended periods of time such that any selected scene can be evaluated at many different sun angles and under many different aerosol and cloud conditions. The experimental concept is that for each scene, sets of images acquired at the same solar scattering angle but under various atmospheric clarities can be iteratively processed to yield successive approximations for each target's true inherent contrast which will converge to a definable best estimate. Continuing work in the refinement of this process and its enabling software is in progress.

3.3 Composite Data Display

In keeping with the generalized goal of developing a fully integrated HSI/WSI composite system, several inter-related tasks have undergone exploratory development resulting in a variety of mock-up prototypes. One of these prototype concepts related to improving the system's data display interface is shown in Figure 3-7.

The current version of the HSI/WSI system treats the two video inputs, one from the HSI camera and one from the WSI camera, independently throughout the acquisition, processing and archival sequences. Thus, under normal conditions, the operator can only observe the visibility and cloud cover output products alternately and intermittently on the system's video monitor. In order to make the display of these products more readily amenable to operator review and assessment, the composite display of Figure 3-7 was devised.

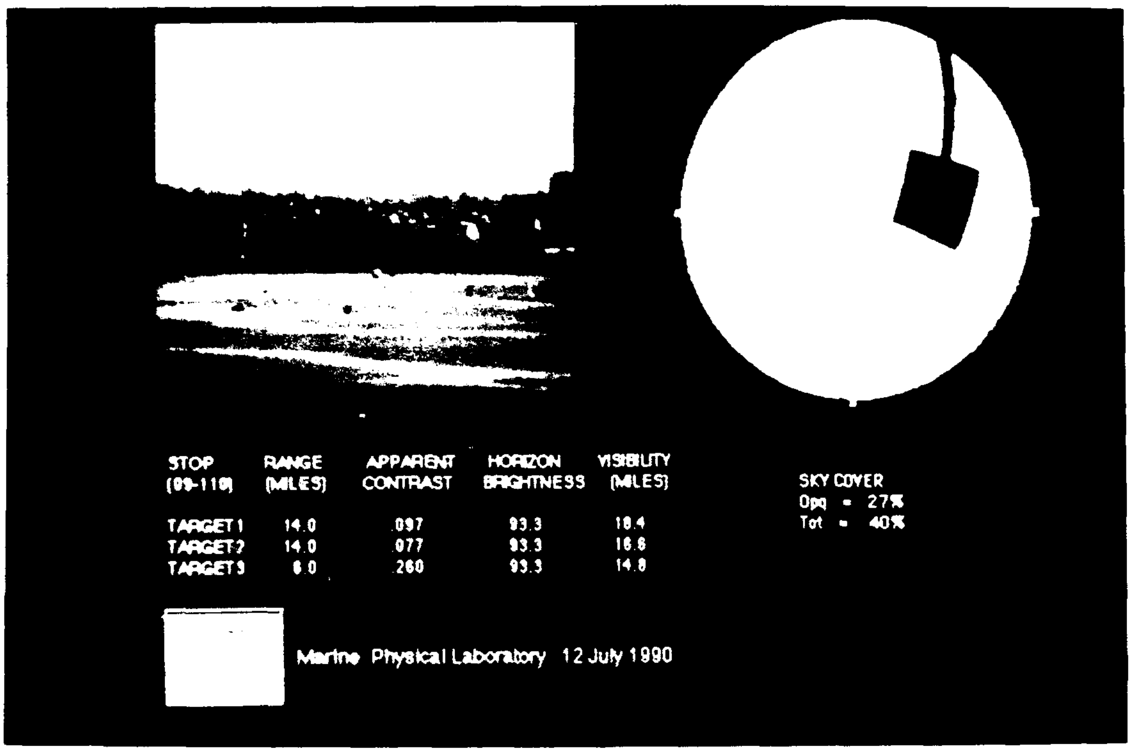


Fig. 3-7 Composite HSI/WSI Display Format

The composite display illustrated in Figure 3-7 was created as an after the fact image retrieval and manipulation exercise. That is both the visibility determination and the cloud cover determination had been previously made and archived in their individual locations on the system archival tape, and subsequently were retrieved, combined as a single image and redisplayed. In its current state of development, this composite image is not available in realtime. It does illustrate, however, an extremely complete specification of the local state of the atmosphere.

Software oriented toward windowing multimedia products into the same display image is currently being developed for use with the HSI/WSI following the display layout shown in Figure 3-7. The goal for this composite display is to update the visibility scene image and its derived numeric products every one to two minutes and update the cloud cover image with its numeric products every fifteen minutes. These temporal increments are reasonably arbitrary at this time, but should be typical of the eventual user options.

4.0 PRELIMINARY NIGHT SYSTEM CONFIGURATIONS

In keeping with the expressed goals of the technical effort reported herein, significant mockup and testing was directed toward low light level systems. The primary intent being to produce an improved system suitable for both day and night all weather operation. Two techniques were evaluated for applicability. The inherent on-chip integration available via charge injection techniques with the CIDTEC camera was an initial and obvious candidate. The addition of an image intensifier element to the camera assembly was the second. Both techniques were successfully tested under varying degrees of low level illumination leading to the redefinition of the desired technical approach.

4.1 Injection Inhibit System

The sensor sub-system used in the HSI is the CID 2710 which incorporates CIDTEC's exclusive Charge Injection Device (CID) sensor into a high-quality, solid state, monochrome RS-170 camera.(Ref. Vol. II)

"The Charge Injection Device is an X-Y addressable image sensor organized so that photon-generated charge can be read at each sensing site (pixel) through local charge transfer. Injection into the underlying substrate is used to clear each pixel of signal charge and start a new signal integration period (television frame time). These images are fabricated in an epitaxial layer; the epitaxial junction is reverse biased and used as a common collector to remove the injected charge from the device. The consequences of this organization are numerous. Since charge is sensed locally, there are no paths along which optical overloads or defects (black or white faults) can propagate. Charge transfer losses are not cumulative. Pixels can be contiguous, leading to high modulation transfer function and high quantum efficiency. The sensor has inherently low dark current; the depletion region of each pixel is smaller than the photo sensitive region and inversion charge can be used to quench surface leakage current. Read-out can be non-destructive allowing on-chip signal processing, and the X-Y addressable array can be random accessed." (Grafinger & Michon)

The HSI system takes advantage of the inherent characteristics of the CID 2710 camera system to address several low light level measurement scenarios without the need for external image intensification. This is accomplished by implementing the Inject Inhibit function available in the standard camera configuration. In this mode, normal destructive readout is interrupted by the Inject Inhibit function which permits the imager to integrate for longer than one frame time. The 2710 continues to integrate as long as the Inject Inhibit function is engaged, facilitating user controlled time exposure. Several mock-up circuit boards were built by MPL to enable the selection of integration intervals ranging between 2 and 200 frames. At standard video rates of 30 frames per second, these integration intervals represent roughly 60 milliseconds upward to 6 seconds. The electronic circuitry required to generate these timing intervals for insertion into the camera's control logic is documented in Volume II. The control circuit housing is illustrated in Figure 4-1.

As one might expect, once an arbitrary integration time not equal to 1/30 Sec is chosen, a non-standard condition is presented to the control computer and its on-board digitizing frame grabber. The Imaging Technology Inc. FG-100 board used in the original HSI daytime only system is not readily adaptable to the acquisition of video imagery at non-RS-170 rates. Consequently, to enable the use of operator selected discrete but arbitrary integration intervals, a different frame grabber was necessary. Fortunately, the same vendor was able to provide a modification, designated the VS-100, that would accept external control and recognize imagery presented at various intervals. Unfortunately, interfacing the VS-100 frame grabber as a retrofit to the WSI control computer became a non-trivial task. Since there

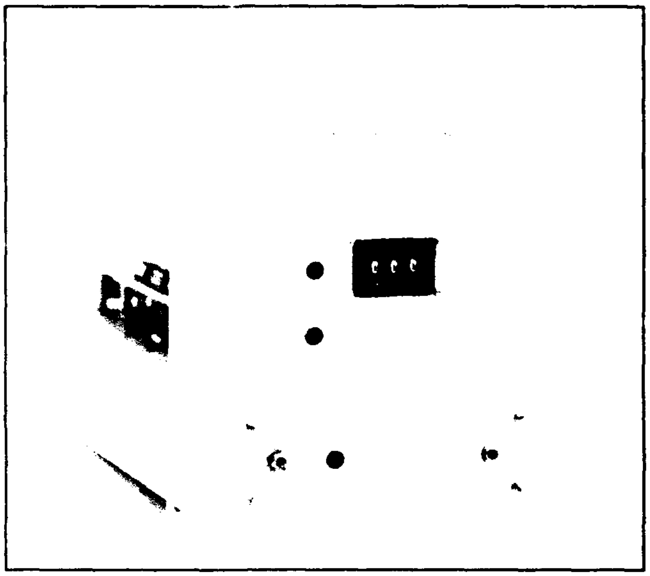


Fig. 4-1 2710 Camera Integration Control Unit

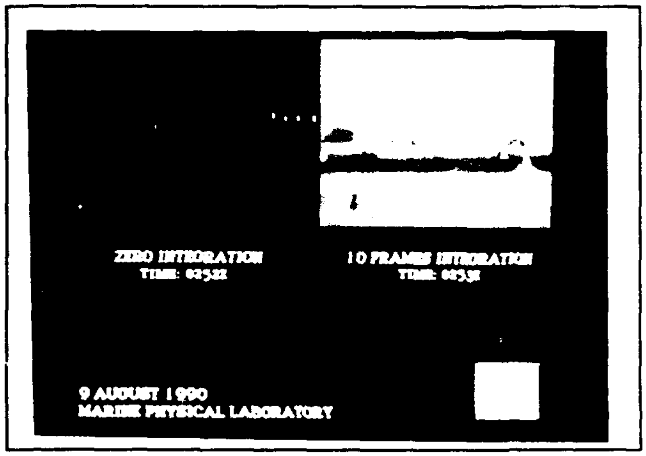


Fig. 4-2 Twilight Imagery, with and without integration

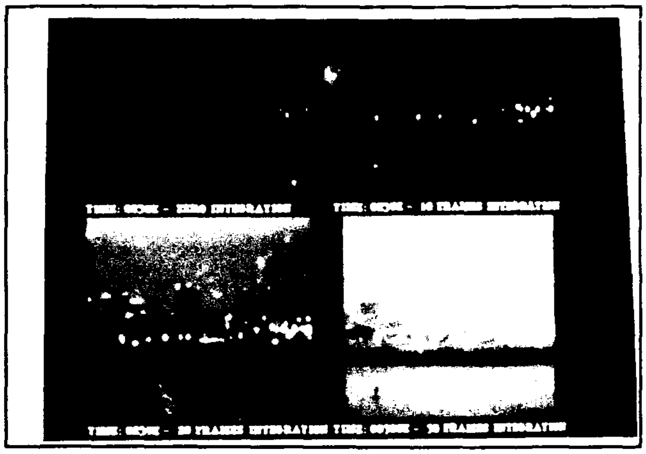


Fig. 4-3 Twilight Imagery, with typical integration intervals

appear to be substantial problems in using the VS-100 board in conjunction with existing SCSI driven peripherals, an alternate frame grabber may be required.

Test sequences involving the acquisition of nighttime imagery using the Inject Inhibit function for image integration have been exercised successfully. Interface limitations have restricted these sequences to relatively short periods of time, since only the 60 Mbyte hard disc could be used as an archival unit while the VS-100 board was on the data bus. This storage limitation however has not seriously impeded the development of the technique. Examples of twilight imagery acquired with the HSI both with and without frame integration are shown in Figures 4-2 and 4-3. In Fig. 4-2, an evening scene as observed from the MPL facility by the HSI system is shown under two conditions. The first, on the viewers left, at 0252Z/1652PST shows a typical twilight scene with zero integration time. The discernment of various buildings used for daytime targeting is still quite good and the detection of a variety of artificial lights within the scene is also clearly possible. One notes that at ten frames of integration, shown on the right at 0253Z/1652PST, the imagery is overly saturated indicating a need for finer increments in the injection innibit selection circuitry. Single frame control over the integration time was anticipated as an eventual system requirement but the prototype controller was not fully debugged at the time of these tests, thus only ten frame increments were available.

Later in the month, the sequence shown in Fig. 4-3 was acquired. At this time, with zero integration at 0258Z only the major lights within the scene are detectable. A minute later at 0259Z with ten frames of integration the scene is about an optimum compromise in discerning daytime target areas and night-time lights. As the integration time increased to 20 and then 30 frames the saturation of the scene and its attendant loss of image detail is apparent. At the time of this report, November 1990, maximum integration times of approximately 100 frames have been acquired without total loss of image quality. For these longer integration intervals to remain useful, consideration must be given to supplementary cooling of the imaging chip and camera.

4.2 Intensified CID System

For low light level applications requiring extreme amplification of the observed luminance field, the integration intervals achievable with the uncooled Inject Inhibit function of the 2710 camera is often inadequate. Thus a second option is required if one chooses to operate at flux levels in the region of 10^{-4} Lumens/sq. ft., eg. the illumination from a clear night sky. The option selected for the HSI was an image intensifier sub-assembly that could be readily retrofitted to the existing 2710 camera. The initial plan was to choose an approach that would lend itself to a simple conversion suitable for our existing collection of both HSI and WSI field systems. The general scheme is illustrated schematically in Figure 4-4. An appropriately modified 2710 camera assembly is shown photographically in Figure 4-5.

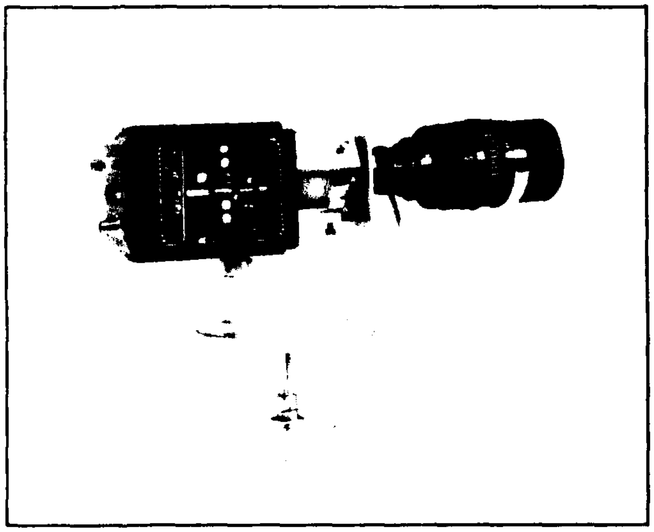


Fig. 4-5 2710 Camera modified with ITT 4767 Intensifier

As one notes from Figure 4-5, the intensified CIDTEC camera is still a relatively small and compact package. In the view shown in Figure 4-5, the camera plus the add-on intensifier, are about the same length as its 100mm fixed focal length lens. Also note that the side plate of the camera housing has been relieved to allow forced air cooling of the video circuitry, a modification imposed on the original daylight only version of the HSI/WSI system.

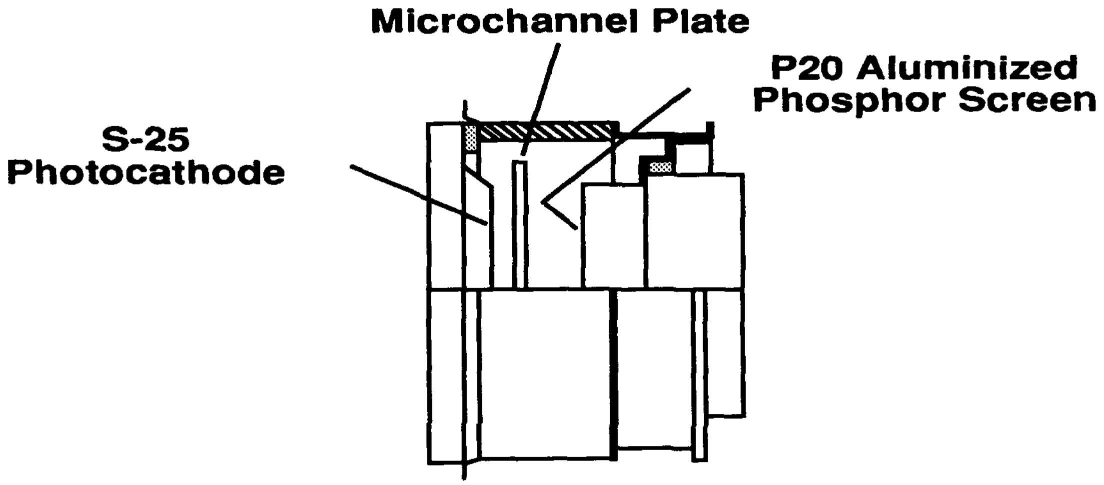
The adaptation of the 4767 intensifier to an existing 2710 camera system was straight forward. The 4767 intensifier coupled to an appropriate fiber optic taper was delivered by ITT already attached to a CID 21-28 solid state area array. The CID 21-28 is plug compatible with the CIDTEC 2700 series camera, so system modifications by MPL were restricted prima-ily to revision of the camera/intensifier support stage and high voltage power supply housing.

In addition to the substantial luminous gain anticipated from the intensified system, i.e., ~ 20,000, another highly desirable feature was the ability to operate the camera at its normal 30 frame/sec video rate. This feature, all others being equal, was attractive in that very little downstream hardware or software revisions would be necessary. The existing control computer with all of the joint HSI/WSI software would be directly transferable to the nighttime application. No adjustments would be required for non-standard video digitization, and data logging procedures therefore would be straight forward. All in all, a very attractive, although not particularly inexpensive upgrade. Standard, no tricks night vision related intensifiers, like the 4767 used in this prototype system, cost on the order of $15,000 in 1988 dollars. The question quickly becomes: does the gain justify the cost? It was decided that if the intent was to modify the HSI to measure the apparent contrast of naturally occurring targets at night, then the gain of the intensified system would indeed be necessary. Thus, an operational mock-up was fabricated and packaged for testing. The initial test goals were to establish the optimum Intensifier gain needed to produce night imagery of suitable quality. It was desired to acquire imagery at illumination levels on the order 10^{-4} lumens/ft^2, approximating the flux levels anticipated under quarter moon conditions.

Initial operations using the intensified system were conducted in the MPL calibration facility dark room to provide reasonable operator training at minimal risk from unintended, spurious light contamination. Subsequent to these mock-up runs the modified camera subassembly was moved outside for nighttime test runs on the MPL rooftop instrumentation platform. At this point, it quickly became apparent that the local area surrounding the test site was too heavily populated with extraneous lighting. There were very few directions in which the camera could be pointed that did not have several nearby bright lights in the field of view. It was decided to establish a remote field test station about 20 miles east of the city to enable more flexible, yet radiometrically safe test procedures. As it turned out, the remote site was ideal for testing both the inject inhibit function as well as the intensifier modification of the basic 2710 camera.

4.3 Preliminary Test Results

In general, the imagery acquired by the two systems described in Sections 4.1 and 4.2 was as anticipated. That is, the inject inhibit function with moderate cooling



Typical Gen II Image Intensifier

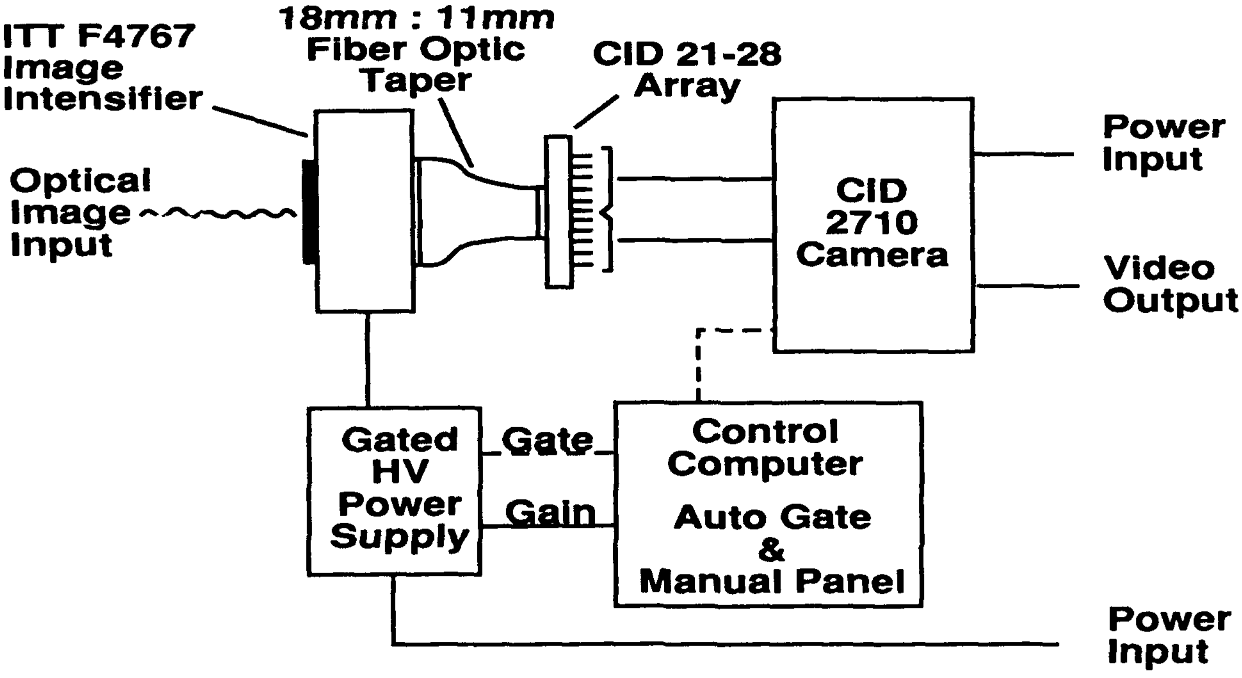


Fig. 4-4

Intensified Camera Block Diagram

enabled on-chip integrations of up to 100 frames without undue signal to noise problems, and the 2767 intensifier modification provided reasonably clear luminous amplifications of 15 to 20 thousand. Examples of test imagery used for system evaluation are reproduced as Figures 4-6, 4-7, and 4-8.

The features illustrated in Figures 4-6, 4-7 and 4-8 represent the performance of the CIDTEC 2710 camera under three different injection inhibit intervals. The imagery was acquired from the RFTS under moonless conditions between 1700 and 2100 PST. Local sunset on 16 Dec 90 was 1645 PST. The cameras path of sight was directed toward Pt. Loma, approximately 30 miles to the west, in a manner similar to that shown in Figure 3-5.

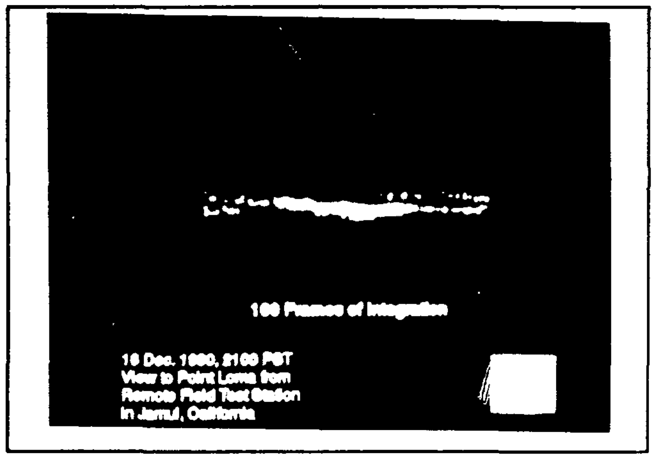


Fig. 4-8 Evening Imagery, 2100 PST with 100 frames of integration

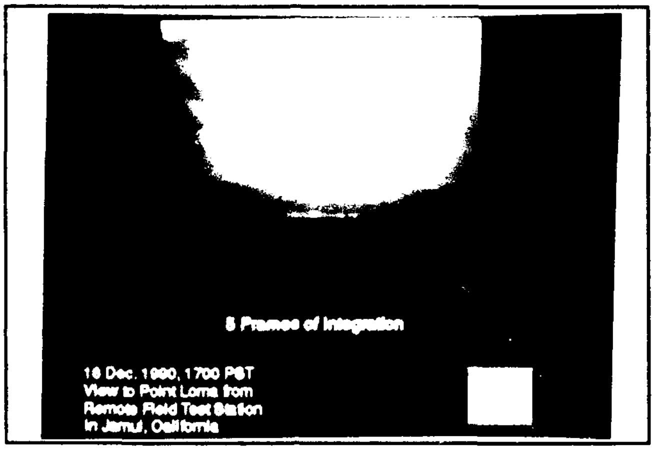


Fig. 4-6 Twilight Imagery, 1700 PST with 5 frames of integration

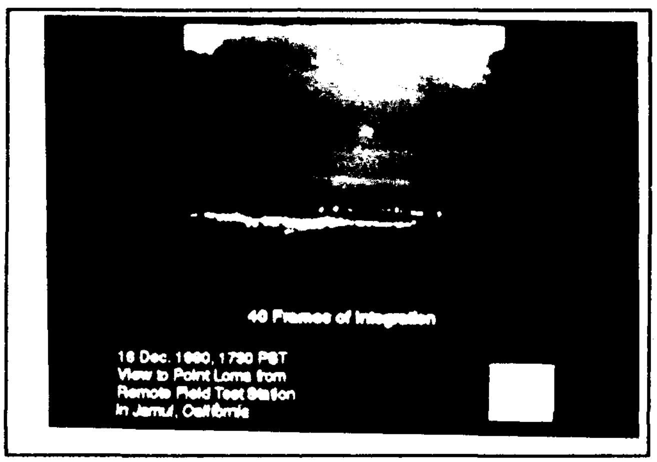


Fig. 4-7 Twilight Imagery, 1730 PST with 40 frames of integration

In Figure 4-6 one should note that the system's integration control circuitry has been modified to enable integration intervals of less than ten frames. In this figure the imagery clearly illustrates the cloudy sky above the horizon, the adjacent dark ocean, the even darker land mass of Pt. Loma slightly below the horizon, and a few city lights just becoming detectable. As annotated on the image, the integration time was for five frames, or approximately 167 milli-seconds.

Thirty minutes later at 1730 PST, the same scene as seen after 40 frames (1.33 sec) of integration is reproduced in Figure 4-7. In this representation, cloud structure is still clearly visible, the distinction between the ocean below the horizon and the Pt. Loma land mass is not discernable, and a full suite of city lights is apparent. The smearing of the central group of city lights, as well as the saturation of the clear night sky above the clouds indicate that 40 frames of integration is more than needed for the detection of distant lights, but is useful for the detection of local cloud conditions.

Much later in the evening at 2100 PST, the image shown as Figure 4-8 was acquired. At this illumination level, the detection of the local horizon and the land ocean interface is irretrievable even at the illustrated 100 frame (3.33 sec) integration interval. However, the detection of the city lights is still clearly achievable. In fact, for the detection of these distant lights the 100 frame interval is too long. The imagery however illustrates the point in question. Injection inhibit techniques should be completely satisfactory for developing the nighttime visibility algorithms based upon the detection of distant lights.

Several examples of nighttime sky and horizon imagery, obtained with the intensified camera system shown in Figure 4-5, are presented in Figures 4-9, 4-10 and 4-11. These scenes were acquired at the RFTS as were the preceding Figures 4-6, 4-7 and 4-8. The procedural differences are annotated on each image. As noted on each, a combination of intensifier gain and injection inhibit integration mode was used to obtain the sample imagery. During the several night sequences conducted during this early 1990 period, a variety of system problems were encountered, some of which are illustrated in Figures 4-9, 4-10 and 4-11.

In Figure 4-9, the camera was equipped with a standard 50mm lens and directed toward a local, non-illuminated cloud field which was barely discernable by the fully dark adapted operator. As in each of the intensified examples, the intensifier control voltage and injection inhibit intervals were adjusted to maintain optimum

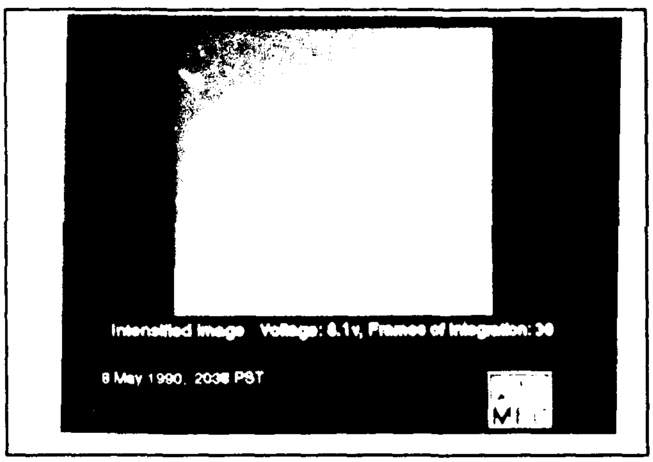


Fig. 4-9 Intensified Imagery, Normal 50mm Lens

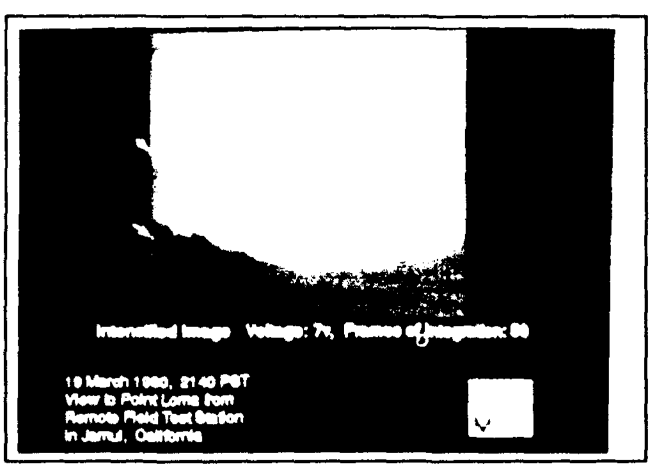


Fig. 4-10 Intensified Imagery, Telephoto with Noise

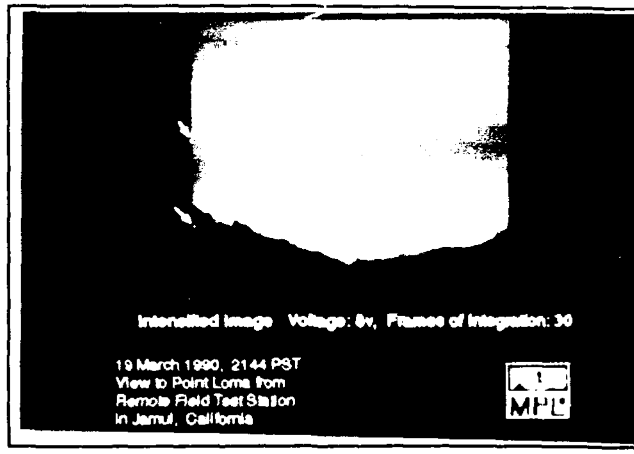


Fig. 4-11 Intensified Imagery, Telephoto, City Lights

image quality. The intensifier control voltage is adjustable between zero and ten volts resulting in a typical luminous gain of approximately 10,000, thus at the 8.1 volts indicated on the image in Figure 4-9, one can assume an intensifier gain of approximately 8,000. Integration intervals are used as smoothing operators to minimize electrical/electronic noise levels. In the relative clean image of Figure 4-9, acquired two hours after local sunset (1835PST), typical intensifier flaws near the left edge of the scene are identified by the superimposed arrows. Flaws of this sort are of little impact upon cloud detection algorithms but could present serious problems to procedures designed for the automatic detection of distant lights. The main point illustrated by Figure 4-9 however, is that for nighttime cloud detection, the intensified system is a completely viable option. In this application, radiometric sensitivity would not be a limiting factor in the overall system design.

Figures 4-10 and 4-11 represent images acquired in telephoto mode, similar to those shown in Figures 4-6 through 4-8. These two scenes taken approximately 3 1/2 hours after local sunset represent two different combinations of intensifier gain and integration interval. They also illustrate typical system noise artifacts that require a variety of packaging, electrical shielding and power supply sophistications to insure adequate suppression. While not technically intractable, the suppression of these irregularities, either in software or hardware, is an additional task requiring design complexity that is unnecessary in systems running with injection inhibit mode only.

In the Figure 4-10 image, the camera is running at an intensifier luminous gain of about 7,000, with 50 frames of injection inhibit. Several image defects are readily visible. The intensifier flaws noted previously in Figure

4-9 and annotated by the small superimposed arrows are, as expected, still present. Additionally, one can clearly discern the narrow band of bright spots running horizontally across the top of the image. This band was intermittent and its source not identified during this test episode. Note that it does not appear in the imagery of Figure 4-11 acquired four minutes later at a slightly different gain configuration. There is a diagonal line pattern rolling through the imagery of both Figures 4-10 and 4-11 which is normally attributable to electrical power problems, but which was not isolated during this episode.

From the imagery acquired during these test episodes, all similar in nature to Figures 4-10 and 4-11 but at a broad variety of gain configurations, several illustrative points became clear. The intensified system, used in conjunction with a judicious amount of injection inhibit to smooth out undesirable image graininess, could readily acquire nighttime imagery suitable for both cloud discernment and the detection of distant lights. It is also clear, and not unexpected, that the radiometric sensitivities needed for cloud detection and distant light detection are quite different. As shown in Figure 4-11 the low cloud layers are not yet clearly defined at the illustrated gain, while many of the city lights are already at levels of image saturation. Thus, increasing the gain configuration to the levels required for contrast measurements under moonlit conditions would surely result in severe image contamination by local light sources, adding yet another level of control complexity needed for implementation of the intensified system.

Having acquired satisfactory sample imagery under twilight and full nighttime illumination levels with both the inject inhibit and full intensified procedures, several options were now available for defining the course of new nighttime system's development. Several issues, not all technical, required consideration in order to select the most appropriate approach for further hardware and software specification and development. Some of the more technically oriented features, most of which were explored during the mock-up exercises which created Figures 4-6 through 4-11, are listed in Table 4.1.

After a review of the features summarized in Table 4.1, and sample imagery similar to that shown in Figures 4-6 through 4-11, the selection seemed to boil down to a high gain complex and relatively expensive system that could measure nighttime contrast, versus a low gain, simple and relatively inexpensive system that could not. In the end it was a feature not listed in Table 4.1, that drove the decision.

Whereas visibility during daytime hours is determined by the apparent contrast between a target and the adjacent horizon sky, visibility at night is not. Normal practice during nighttime hours is to use the detection of distant lights as the criteria for establishing "visibility". It is thus not inappropriate to design the nighttime HSI to operate on the same basis. Thus if one requires only that the HSI system be able to detect and identify the nature of preselected lights within its field of view, then the need for extremely high photometric gain is substantially reduced. In fact for this task, the injection inhibit mode of operation seems quite adequate. Since choosing the injection inhibit approach is a relatively "fail-safe" endeavor, the choice was made to defer further development of the image intensifier version, and to proceed with the simpler packaging, and refinement of the injection inhibit technique. Refinement, testing and technique development related to this mode of nighttime operations are currently in progress.

5.0 SELF CALIBRATION OF VISIBILITY TARGETS

In an attempt to help ensure observational compatibilities and representativeness, "meteorological visibility by day is defined as the greatest distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognized, when observed against a background of fog or sky". Thus, as one might well expect, the prime requirement for reliable determination of visibility is an ample supply of suitable targets, well distributed in range and azimuth. On the one hand it is important to make use of all objects in the horizon scan imagery that may serve as visibility targets, while on the other hand, because of their intrinsic properties, all potential targets in a given situation are not equally effective determinants of the local visibility. The basic properties of each target must be predefined, including not only the distance from the observation point to the target, but also the inherent contrast of the target, and the contrast threshold required for detection. As noted earlier, range and detection threshold can be readily pre-established for the HSI system, leaving target inherent contrast as the only input parameter not easily specified.

Whereas ideal non-reflecting black targets always have a relative contrast of -1 against the adjacent horizon sky, the reflectivity of even the darkest natural targets is seldom zero, requiring therefore substantial care in specifying their estimated inherent contrasts. The sensitivity of visibility determinations to the uncertainties in the estimates of the inherent contrast as an input variable is illustrated in Fig. 5-1 from Johnson, et al, 1989. Note

NIGHT VISIBILITY SYSTEM SELECTION FEATURES

Feature No.	INJECTION INHIBIT OPTION	IMAGE INTENSIFIER OPTION
1	Runs using existing 2710 camera, un-modified	Requires additional intensified chip sub-assembly
2	Runs at non-standard frame rates	Runs at standard 30 frame/sec rate
3	100 frame integration insufficient for night contrasts	Gain sufficient for night contrasts at 1/4 moon
4	Requires VS-100 Variable Rate Frame Grabber	Runs with existing FG-100 Frame Grabber
5	VS-100 has SCSI interface incompatibility	FG-100 runs with existing SCSI
6	New Fabs Required: None to Camera None to Housing Additional Exterior Cables Precision Frame Counter & Trigger	New Fabs Required: New Camera stage New Housing for HV supply Additional Interior HV loom Intensifier support frame
7	New Software Req: Integration Time control code VS-100 trigger control code Image transfer to EXABYTE	New Software Req. Flux control algorithm & code Gain control algorithm & code Current limit default flag
8	Image quality stable up to moderate integr. times	Image quality falls off at Low & High gains
9	Un-modified imager radiometrically robust	Intensified chip radiometrically fragile
10	Electronically simple	Electronically complex

Table 4.1 Night Visibility System Selection Features

in particular that visibility determinations are not sensitive to errors in the input values of inherent contrast, C_0, when the object is near the maximum distance at which it can be seen, such that the apparent contrast is close to the threshold detection contrast. However, the error sensitivity increases substantially for nearby targets in good visibility conditions when the measured apparent contrast is relatively large. Thus, the relative accuracy of visibility as determined from a given non-standard target is in part a function of the visibility itself.

In view of the foregoing comments, and considering the vulnerability of the target to fluctuations in C_0 due to changes in the directional distribution of lighting reaching the target from the sun, sky and surrounding terrain, it seems only appropriate to try and teach the HSI to determine for itself the best instantaneous value of any targets most probable inherent contrast. The continuing acquisition of a suitably extensive and diverse sample of HSI imagery, and the development of appropriate procedures for the automated determination of any targets instantaneous inherent contrast are currently in progress.

5.1 Procedural Concepts

The procedure for developing a technique for the self-determination of target inherent contrasts by the HSI system is built around the consideration of an idealized test environment. That is, consider the situation of a staring imager observing a stationary scene along a horizontally stratified line of sight which contains an array of black targets uniformly distributed at ranges between one and arbitrarily one hundred miles.

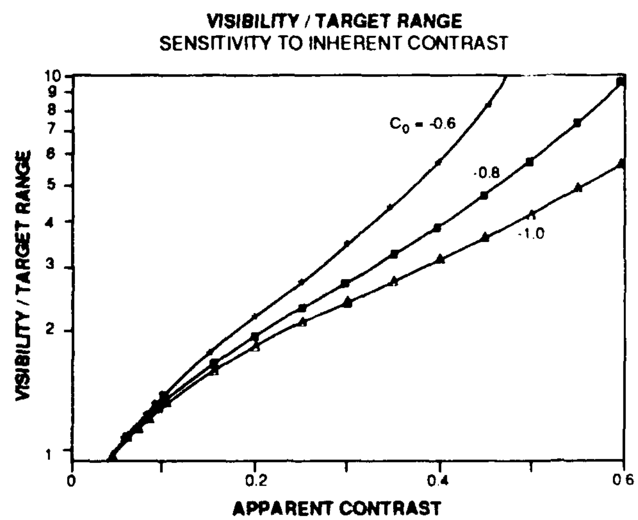


Fig. 5-1 Sensitivity of V/r ratio to Inherent Contrast

Recalling that, with the horizon sky as the background and with visibility targets selected on or near that local horizon, the HSI systems operative equation becomes

$\frac{V}{r} = \ln\left(\frac{\varepsilon}{C_o}\right) \Big/ \ln\left(\frac{C_r}{C_o}\right)$, one may then observe a relatively straight forward procedure leading to self calibration. With range, r, and threshold contrast ε, prespecified system constants, system performance will be driven by the measured apparent contrast, C_r, and the specified inherent contrast, C_o, of each target against the horizon sky. In the idealized test environment, if one assumes that the measured values of C_r are consistently accurate, and of suitable precision to insure reliable contrast discriminations at the threshold level specified by ε, then only erroneous specification of target inherent contrasts, C_o, preclude all targets being equally valid as determinants of Visibility, V. To the extent that this contention is true, then in any test scene the variability in the assessment of visibility should be correctable by the process of determining how the assigned values of C_o vary from their true value and making the appropriate reassignment. (In situations where the true values of C_o are substantially different from the range of -0.9 and -1.0, some correction of the form suggested by Figure 5-1 might be desirable.)

In order to test the efficacy of implementing this self-determination procedure, one must establish a reasonably complete data base. The test scene need not be azimuthally small in extent, but should be rich in range distributed targets. It is important that horizon sky regions be at small scattering angles from their associated targets such that equivalent path radiances are associated with each target/horizon sky pair. Thus, for this test procedure, it may be possible to select a single scene that is suitable for data base development, precluding the need for precision scanning of the full horizon.

Acquisition of daily imagery sets for the development of a prototype data base suitable for this test procedure is currently underway at the MPL facility.

6.0 RECOMMENDATIONS FOR FURTHER ENHANCEMENTS

The use of specially calibrated, computer interfaced video systems for the automatic determination of local visibility and cloud cover has been undergoing refinement and testing both at the Phillips Laboratory test site at OTIS ANGB, Massachusetts, and at the Marine Physical Laboratory in San Diego, California.

The operation and use of these systems as prototype test beds is rapidly becoming a mature technology, especially in their current daytime only operational configurations. As with most systems which attempt to mimic human behaviors, however, there is always substantial room for refinement, particularly so when one of the desired behaviors involves an instrument to mimic human visual performances. As commented upon in the previous references and in Vol. II, when encountering unusual or nonstandard situations the human can revise its operating rules to adapt to the newly encountered situation and press on; for the machine it is much more difficult. In the case of many relatively simplistic "rule following" systems, coping with a new, undefined situation becomes impossible, and a default response is all that can be offered. So it is with the current versions of the HSI & WSI systems. They perform as expected except when they encounter what they consider non-standard, i. e. non-defined situations. For the HSI, this means when it gets too dark, and/or when there are no appropriate targets within its field of view. Unlike its human counterpart, it doesn't yet know how to improvise.

Recent developments in both hardware and software techniques have led us to believe that nightfall need not put the HSI to sleep, but that it can be modified to cope with nighttime flux levels. Additionally, preliminary studies using selected imagery previously archived by the HSI system are currently exploring techniques to address the problems encountered when there is an inadequacy of targets for reliable visibility estimates.

The proposals contained in the following paragraphs are for studies to provide solutions to several existing shortcomings in the current operational version of the HSI, to extend its capabilities into several modes of nighttime operations, and to suggest additional arenas for interactive application and enhancement of its output products.

6.1 HSI Self-determination of Optimum Inherent Contrast Estimates

Field testing to date, both at OTIS ANGB and at the Marine Physical Laboratory leave little doubt that the most severe limitation on HSI daytime performance is the dearth of suitable targets. "Suitable" for appropriate use by the automatic HSI algorithm means adequately black and at near detection threshold range. The size of the target is not nearly as important to the HSI as to the human. With the human, the requirement for a given target size stems from the fact that the human is not measuring apparent contrast directly but sensing a barely detectable target at a previously learned range. The observation that a given target is at visual threshold implies an apparent contrast of roughly .05 only if the target is the appropriate size and other psychophysical criteria are met. By measuring the apparent contrast directly, the HSI avoids this requirement for a given target size. Target size is ideally limited only by effective field of view (FOV) per pixel. For the HSI a 4.5 degree FOV is displayed at 486 pixel resolution yielding approximately 0.01 degree angular resolution. Thus the camera could ideally detect a one pixel target as small as about one foot at a distance of one mile. In actual practice, the system is set up to use targets of several pixel extent so that only the darkest portion of the target may be selected for use in the measurement of apparent target contrast against its background horizon.

Thus, from a procedural point of view, it is reasonable to assert that the major source of uncertainty in HSI generated estimates of visibility, i.e. the distance at which the horizontal contrast transmittance has been reduced to the detection/identification threshold, is in the initial assignment of each targets inherent contrast, C_0, at the moment of measurement. This assignment is currently made by the system operator based upon whatever prior knowledge is available to him and within the context of his technical experience. As illustrated in the previous references, an estimate of about -0.8 is reasonable for many natural targets, and will yield useful approximations. It is well known however, that the inherent contrast of even very dark targets varies substantially with sun angle, season, etc. For optimum performance then, the HSI must have a better procedure to generate the estimates upon which its algorithms depend.

It is recommended that a procedure be defined, and tested using existing archived data, that will allow the system to teach itself what values of inherent contrast, C_0, it should use for any particular determination of daytime visibility. The procedure would be of the following form:

a) From the existing HSI data base at either site, select a set of images, each of the same target scene, but each measured under a different degree of atmospheric turbidity spanning the range from very clear to very turbid, i. e. from very high visibility to very low visibility, and at each hour of the day. Choose a scene containing the broadest available range distribution of targets as the input to this special subset.

b) Run iterative interactive sequences of AUTOVIS adjusting assigned values of inherent contrast for those targets at the appropriately determined range to minimize the variance in computed visibility derived from these targets.

c) Analyze resultant sorted C_0 catalog using Program COSTUDY to establish sensitivity of technique. C_0 values should converge to a reasonably well behaved minimum value for each zenith angle/season category.

d) Iterate procedure to establish applicability to non-dark target selections.

6.2. Injection Inhibit Techniques for Visibility at Night

Although image intensification techniques show good promise for nighttime contrast transmittance determinations, the use of the HSI cameras built-in injection inhibit capability may provide a conceptually simpler approach for nighttime techniques. To take advantage of the injection inhibit mode of operation, which is essentially an on-chip time integration technique, it is preferable to shift from the determination of contrast transmittance to the simpler form of radiance transmittance. In this procedure the visibility targets are lights that are detectable within each scene, and the camera is used in classical transmissometer mode. The detection range of distant lights becomes the parameter to be associated with visibility.

To enable the acquisition of night scenes under computer control while the camera is in the integration mode requires two hardware implementations. The first is a reliable timer/counter circuit which can issue the proper start-stop commands in order to select the desired number of video frames to be included in the image integration time. The second is a video frame grabber that can be interfaced in such a way that it can, under switch command, grab and digitize video imagery that is not necessarily within the standard 30 frame per second format. That is, the camera chip must be able to accumulate energy over multiples of the normal frame time before sending the resultant image to the grabber for digitization, and the frame grabber must be able to accept the images at whatever rate the camera sends them.

Both of these enabling techniques have been demonstrated at the Marine Physical Laboratory, and a prototype configuration of an HSI system using these techniques is currently operational. Nighttime imagery demonstrating injection inhibit sequences of up to 100 frame times, i. e. over three seconds, has been successfully grabbed, digitized, archived to tape, and retrieved for analysis. Thus the fundamental requirements for acquiring nighttime data suitable for transmissometer mode technique development seem well in hand.

It is recommended at this point to proceed in the following manner:

a) Refine the injection inhibit control circuitry to enable the reliable selection of integration times from as few as two to three frames to as high as 100 to 150 frames, and retrofit the circuitry into the existing two HSI systems.

b) Initiate the acquisition of nighttime imagery containing a broad selection of both near and far light sources which are identifiable in terms of location and intensity. Provide for installation within the HSI FOV at least one 25 candle light as a calibration reference point.

c) Evaluate night imagery data base to determine maximum ranges detectable, appropriate integration times for reproducible detection levels, and related system characterization parameters.

d) For selected lights of appropriately similar intensities, evaluate the technique for obtaining a nighttime average attenuation coefficient using the HSI to measure lights of opportunity as suggested by Gordon (1989) attached.

6.3 Extreme Wide Angle System for Combined Visibility & Cloud Cover Imagery

The existing composite HSI/WSI system as described in Johnson (1989) is a relatively large mechanical package. The requirement for viewing the entire 360° horizon with high angular resolution and high azimuthal reproducibility drove the prototype design to include a telephoto lens yielding resolutions of approximately 0.01 degree per pixel, eg. each pixel resolution about one foot at one mile. Similarly, the desire for ± 1 pixel reproducibility in azimuth required the use of a precision rotary table. Whereas both of these hardware choices have performed well, yielding exceptionally well defined imagery, there has been a continuing desire to merge a simpler configuration with the whole sky imager to yield a single optical/mechanical package having fewer moving parts, thus higher reliability, and a more compact form.

Recent design revisions to the Whole Sky Imager for enabling night operation has led to a review of available wide angle lens systems. One of the more intriguing finds was a large, extremely wide angle, i.e. 220° FOV, lens that offers several conceptual options.

If one were to assume that since the rules for human estimates of visibility recommend the use of black targets at least one half degree in subtense, then it might be reasonable to assume that an instrument, eg. the HSI, could use the same criteria for its targets. This argument is faulty to the degree that humans regularly use targets less than 1/2° wide and generate useful estimates of visibility, and so does the HSI system. The basic question is, can the machine do just as well using only targets meeting the 1/2° size criterion? If it can be shown that the answer is yes, then the use of an extreme wide angle lens for joint HSI/WSI imagery becomes a viable option.

A single 220° FOV lens not only sees the entire 180° sky dome in its observed scene, it also sees approximately 20° below the local horizon which puts the location of most normal visibility targets well within its useful image. If this class lens can be adapted to the configuration used by a newly revised WSI design, it will have a per pixel resolution of approximately 0.4°, a suitable match to the desired 0.5°. It is not unrealistic to consider pixel resolutions of 0.1° should larger imaging chips become available.

As one might expect, lenses of this class are not inexpensive. Therefore, before a mock-up in hardware is contemplated, several analytic procedures should be initiated and reviewed to define specific feature vs cost relationships. The relative simplicity of a fully staring vs mechanically scanning system is attractive, as is the sharing of a common optical sub-assembly by both HSI & WSI subsystems. However, the procedural complexities of flux control and augmented software development will obviously be somewhat mitigating effects.

This recommendation is to pursue the repackaging concept to the extent of establishing its technical viability. The procedure to be followed is primarily analysis of existing data, and the analysis of an auxiliary data set to be acquired by existing hardware. In general, the approach would be to synthesize from HSI imagery, pseudo targets approximating 0.5° in extent to simulate the resolution of the extreme wide angle system. Then use these large format pseudo targets to determine estimates of visibility and compare with the results from the original high resolution data base.

Use the results from the low resolution simulation outlined above, plus an equivalent evaluation of 0.1° resolution to specify degree of viability for use in automatic visibility determinations. If results are appropriate, review the costs involved for hardware development and submit further recommendations.

7.0 Summary

This two volume report describes the continued development and enhancement of an electro-optical system designed for the automatic acquisition and archival of local horizon imagery specifically tailored to the determination and assessment of daytime sector visibilities and subsequently their spatial and temporal variabilities. Volume I describes the extension of the system's capabilities into the nighttime regime and presents preliminary night imagery suitable for use in the identification of distant lights as visibility targets. Hardware conversions related to the system's control computer and its environmental housing are discussed briefly, as are several software upgrades. The major software enhancement being the modification enabling joint control of the composite HSI/WSI system through the same computer.

Preliminary configurations for nighttime operation are described, and sample imagery from each of two is presented for review. Injection inhibit mode, an inherent characteristic of the Charge Injection Device camera system is chosen as the system of choice for the nighttime detection of distant lights. Similar imagery for an image intensifier based system is also reviewed.

Volume II contains engineering documentation, software documentation, preliminary operations manual and preliminary field test plan. These data previously released as Optical Systems Group Technical Notes are included to supplement, where necessary, the general discussion in Volume I. The annotated summary describing the system software contains revised descriptive material for each sub-routine and new procedural flow charts. Subroutine listings are provided as a sub-appendix delivered under separate cover in accordance with the CDRL Line Item 105.

8.0 Acknowledgements

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